Chapter 4
Competitiveness

This chapter of the Cleaner Technologies Substitutes Assessment (CTSA) presents information on basic issues traditionally important to the competitiveness of a printed wiring board (PWB) manufacturer: the performance characteristics of the making holes conductive (MHC) technologies relative to industry standards; the direct and indirect production costs associated with the MHC technologies; the federal environmental regulations affecting chemicals used in or waste streams generated by a technology; and the implications of an MHC technology choice on global competitiveness. A CTSA weighs these traditional competitiveness issues against issues business leaders now know are equally important: the health and environmental impacts of alternatives products, processes, and technologies. Section 4.1 presents the results of the Performance Demonstration Project. Section 4.2 presents a comparative cost analysis of the MHC technologies. Section 4.3 lists the federal environmental regulations affecting chemicals in the various technologies. Section 4.4 summarizes information pertaining to the international use of the technologies, including reasons for adopting alternatives to electroless copper worldwide.

4.1 PERFORMANCE DEMONSTRATION RESULTS

4.1.1 Background

This section of the CTSA summarizes performance information collected during performance demonstrations of MHC technologies. These demonstrations were conducted at 25 volunteer PWB facilities in the U.S. and Europe, between September and November, 1995. Information from the performance demonstrations, taken in conjunction with risk, cost, and other information in this document, provides a more complete assessment of alternative technologies than has previously been available from one source.

In a joint and collaborative effort, Design for the Environment (DfE) project partners organized and conducted the performance demonstrations. The demonstrations were open to all suppliers of MHC technologies. Prior to the start of the demonstrations, DfE project partners advertised the project and requested participation from all interested suppliers through trade shows, conferences, trade journals, and direct telephone calls.

4.1.2 Performance Demonstration Methodology

The detailed performance demonstration methodology is attached in Appendix F. The general plan for the demonstrations was to collect information about MHC technologies at facilities where the technologies were already in use. The information collected through the demonstrations was intended to provide a “snapshot” of the way the technology was performing at that particular facility at that particular time. It is important to note that the methodology was developed by consensus by a technical workgroup, which included suppliers, trade association representatives, the U.S. Environmental Protection Agency (EPA), and many PWB manufacturers.

Each supplier was asked to submit the names of up to two facilities where they wanted to see the demonstrations of their technology conducted. This selection process encouraged the suppliers to nominate the facilities where their technology was performing at its best. This, in turn, provided for more consistent comparisons across technologies. The sites included 23 production facilities and two supplier testing facilities. While there were no pre-screening requirements for the technologies, the demonstration facilities did have to meet the requirements of the performance demonstration methodology.

For the purposes of the Performance Demonstration Project, the MHC process was defined as everything from the desmear step through 0.1 mil of copper flash plating. In order to minimize differences in performance due to processes outside this defined MHC function, the panels used for testing were all manufactured and drilled at one facility. One hundred panels, described below, were produced. After drilling, three panels were sealed in plastic bags with desiccant and shipped to each test site to be processed through the site's MHC line. All bags containing panels remained sealed until the day of processing.

An on-site observer from the DfE project team was present at each site from the point the bags were opened until processing of the test panels was completed. Observers were present to confirm that all processing was completed according to the methodology and to record data. Each test site's process was completed within one day; MHC processing at all sites was completed over a two month period.

When the MHC processing was completed, the panels were put into sealed bags with desiccant and shipped to a single facility, where they remained until all the panels were collected. At this facility, the panels were electroplated with 1.0 mil of copper followed by a tin-lead etch resist, etched, stripped of tin-lead, solder mask coated, and finished with hot air solder leveling (HASL). A detailed account of the steps taken in this process is included in Appendix F.

After HASL, the microsection coupons were routed out of the panels and sent to Robisan Laboratory Inc. for mechanical testing. The Interconnect Stress Test (IST) coupons were left in panel format. The panels containing the coupons were passed twice through an IR reflow to simulate assembly stress. A detailed protocol describing the IR reflow process is also included in Appendix F. The panels with the IST coupons were then sent to Digital Equipment Corporation of Canada (DEC Canada) for electrical prescreening and electrical testing.

Limitations of Performance Demonstration Methodology

This performance demonstration was designed to provide a snapshot of the performance of different MHC technologies. Because the test sites were not chosen randomly, the sample may not be representative of all PWB manufacturing facilities in the U.S. (although there is no specific reason to believe that they are not representative). In addition, the number of test sites for each type of technology ranged from one to ten. Due to the smaller number of test sites for some technologies, results for these technologies could more easily be due to chance than the results from technologies with more test sites. Statistical relevance cannot be determined.

4.1.3 Test Vehicle Design

All of the test panels were manufactured by H-R Industries, Inc. The test panel measured 24" x 18", laminated to 0.062", with eight layers. Test panels were produced from B and C stage FR4 materials. Artwork, lamination specifications, and a list of the steps taken to manufacture the panels are included in Appendix F.

Each test panel contained 54 test coupons: 27 IST coupons (used for electrical testing) and 27 microsection coupons. IST coupons measured 6.5" x 3/4" and contained 700 interconnecting vias on a seven row by 100 via 0.050" grid. This coupon contained two independent circuits: the post circuit and the plated through-hole (PTH) circuit. The post circuit contained 200 interconnects, and was used to measure post interconnect resistance degradation. The PTH circuit contained 500 interconnects, and was used to measure PTH (barrel) interconnect resistance degradation. IST coupons had either 0.013" or 0.018" holes (finished).

The microsection coupon measured 2" x 2" and contained 100 interconnected vias on a 10 row by 10 via 0.100" grid. It had internal pads at the second and seventh layer and a daisy chain interconnect between the two surfaces of the coupon through the via. Microsection coupons had either 0.013", 0.018", or 0.036" holes (finished).

This study was a snapshot based on products built with B and C stage FR4 materials and this specific board construction. The data cannot necessarily be extrapolated to other board materials or constructions.

4.1.4 Electrical and Microsection Testing Methodology

Electrical Testing Methodology

The IST coupons in panel format were electrically prescreened to determine defects on arrival. The panels were then shipped to another facility for routing of the IST coupons, and were shipped back to DEC Canada for completion of electrical testing.

Electrical testing was completed using the IST technology. IST is an accelerated stress test method used for evaluating the failure modes of PWB interconnect. This method uses DC current to create the required temperatures within the interconnect. There are three principal types of information generated from the IST:

- Initial resistance variability.
- Cycles to failure (barrel integrity).
- Post separation/degradation (post interconnect).

The resistance value for the first internal circuit (PTH circuit) for each coupon was determined. This gives an indication of the resistance variability (plating thickness) between coupons and between panels. The initial resistance testing was also used to determine which coupons had defects on arrival, or were unsuitable for further testing.

The cycles to failure indicate how much stress the individual coupons can withstand before failing to function (measuring barrel integrity). IST coupons contained a second internal circuit (post circuit) used to monitor the resistance degradation of the post interconnect.

The level of electrical degradation in conjunction with the number of cycles completed is used to determine the presence and level of post separation. The relative performance of the internal circuits indicates which of the two internal circuits, the post circuit or the PTH circuit, has the dominant failure mechanism. The draft Institute for Interconnecting and Packaging Electronic Circuits (IPC) IST test method is included in Appendix F.

Mechanical Testing Methodology

The coupons for mechanical testing were sent to Robisan Laboratory Inc. for testing. Mechanical testing consisted of evaluations of metallurgical microsections of plated through-holes in the "as produced" condition and after thermal stress. One test coupon of each hole size from each panel was sectioned. The direction the coupons were microsectioned was determined by visually examining the coupons to determine the direction of best registration to produce the most inner layer circuitry connections in the microsections.

Microsections were stressed per IPC-TM-650, method 2.6.8, included in Appendix F. The plated through-holes were evaluated for compliance to the requirements found in IPC-RB-276. Microsections were examined after final polish, prior to metallurgical microetch, and after microetch.

The original test plan called for selection of IST and microsectioning coupons from similar locations on each panel. Following prescreening, the coupon selection criteria was amended to be based on coupons with the best registration. This resulted in some coupons being selected from areas with known thicker copper (see Results of Electrical Prescreening below).

Four 0.013" IST coupons were selected from each of the three test panels from each test site. Test Site #3 and Test Site #4 had only two available test panels, therefore six coupons were selected from each panel. Three coupons from within six inches of the IST coupons selected were microsectioned from the same panels. In some cases, the desired microsection coupons exhibited misregistration, so next-best locations were used. In all cases, coupons selected were located as close to the center of the panel as possible.

Limitations of Testing Methodology

Fine line evaluations in microsections have always been a point of contention within the industry. Current microsection specifications state that any indication of separation between the hole wall plating and the inner layer is sufficient grounds to reject the product. An indication of post separation would be a line on the microsection thicker than what normally appears with electroless copper technology (normal average: 0.02 - 0.04 mils). Separation may also be determined by a variation in the thickness of the line across the inner layer connection, especially on electroless deposits that are very thin. The rationale for these rejection criteria is that product with post separation degrades with time and temperature cycling.

With traditional electroless copper products where post separation is present, it can usually be determined where the separation occurs: between the electroless and foil, within the electroless, or between the electroless and the electrolytic plating. This determination often helps in troubleshooting the plating process. In this study, some of the alternative technologies resulted in no line at all after microetch on the microsections. This posed a problem in interpretation of results. If traditional criteria are used to determine inner layer separation (i.e., the line of demarcation is thicker on some inner connects than others, and the electroless can be seen as continuous between the inner layer and plated copper), then accurate evaluations of product with no lines would not be possible. In this study, the criteria used on "no line" products was that if the sections exhibited any line of demarcation after microetch, the product is considered to have inner layer separation.

This issue is significant to the PWB industry because there remains a question about the relationship between the appearance of a line on the microsection to the performance of a board. Traditionally (with electroless copper products), the appearance of a line thicker than normal electroless line is considered to be post separation, and the board is scrapped. However, there are no criteria for how to evaluate "no line" products. In addition, there are no official means of determining when "a little separation" is significant to the performance of the board.

IST is not a subjective test and is not dependent upon the presence or absence of a line in a microsection after microetch. The test provides a relative number of IST cycles necessary to cause a significant rise in resistance in the post interconnect. This number of cycles may be used to predict interconnect performance. Tests such as this, when correlated with microsections, can be useful in determining how to interpret "no line" product characteristics. In addition, IST may be able to determine levels of post separation.

The figures included in Appendix F in the IPC IST test method show various failure mechanisms exhibited by different test sites and panels. Future industry studies must determine the relevance of these curves to performance, based on number of cycles needed to raise the resistance as well as the amount of change in resistance. Definitions for "marginal" and "gross" separations may be tied to life-cycle testing and subsequently related to class of boards produced.

4.1.5 Results

Product performance for this study was divided into two functions: PTH cycles to failure and the integrity of the bond between the internal lands (post) and the PTH. The PTH cycles to failure observed in this study is a function of both electrolytic plating and the MHC process. The results indicate that each MHC technology has the capability to achieve comparable (or superior) levels of performance to electroless copper.

Results are presented in this section for all three stages of testing conducted:

1. Electrical prescreening, which included tests for:

- Defects on arrival based on resistance measurements.
- Print and etch variability based on resistance distribution of the post circuit.
- Plating variability based on resistance distribution of the PTH circuit.

2. Microsection evaluation, which examined:

- Plating voids.
- Drill smear.
- Resin recession.
- Post separation.
- Average copper plating thickness.

3. Interconnect stress testing, which measured:

- Mean cycles to failure of the PTH interconnect.
- Post degradation/separation within the post interconnect.

Results of Electrical Prescreening

Seventy-four of 75 test panels from 25 test facilities were returned. One of the 74 proved to be untestable due to missing inner layers. The results of the prescreening will be reported in the following categories: defects on arrival (unacceptable for testing), print and etch variability, and plating (thickness) variability.

Defects on Arrival. A total of 1,971 coupons from the 73 panels each received two resistance measurements using a four wire resistance meter. The total number of holes tested was 1.4 million. As shown in Table 4.1, one percent (19) of coupons were found to be defective, and were considered unacceptable for IST testing because of opens and shorts.

Table 4.1 Defective Coupons Found at Prescreening

Test Site #	MHC Technology	Opens	Shorts
1	Electroless		4
3	Electroless	1	2
11	Graphite	2	
12	Graphite		5
14	Palladium	1	
16	Palladium	2	
20	Palladium	2	

Following an inspection of the defective coupons, the opens were found to be caused by voiding, usually within a single via. Shorts were caused by misregistration. The type of MHC technology did not contribute to the shorts.

Print and Etch Variability. The resistance distribution for the post circuit was determined. Throughout manufacturing, the layers/panels were processed in the same orientation, which provided an opportunity to measure resistance distributions for each coupon/panel. The distribution proved very consistent. This result confirms that inner layer printing and etching did not contribute to overall resistance variability. Table 4.2 depicts the mean post circuit resistance for five 0.013" coupon locations (in milliohms) for all 73 panels.

Table 4.2 Mean Post Circuit Resistance Measurements, in Milliohms
(coupon locations on panel)

409		405
	399	
415		411

Plating Variability. The resistance distribution for the PTH circuit was determined as an indicator of variability. The results indicated that overall resistance variability was due to plating thickness variability rather than print and etch variability. Table 4.3 depicts the mean PTH circuit resistance for five 0.013" coupon locations (in milliohms) for all 73 panels.

Table 4.3 Mean PTH Circuit Resistance Measurements, in Milliohms
(coupon locations on panel)

254		239
	244	
241		225

The PTH interconnect resistance distribution showed the electrolytic copper plating increased in thickness from the top to the bottom of each panel. Copper thickness variability was calculated to be 0.0003" thicker at the bottom compared to the top of each panel. Resistance variability, based on 54 measurements per panel, was also found from right to left on the panels. Inconsistent drill registration or outer layer etching was thought to be the most probable cause of this variability. When a number of holes break out of their pads, it increases the internal copper area, causing the resistance to decrease. This reduction in resistance creates the impression the coupons have thicker copper.

Table 4.4 lists the means and standard deviation of all PTH resistance measurements and the levels of correlation among panels observed at each site. As seen in Table 4.4, copper plating distribution at each site was good. Plating cells and rack/panel locations did not create large variability that could affect the results of each test site. Because resistance (plating thickness) distribution was also consistent among test sites, relative comparisons among the different MHC technology sites can be made. Only one site, Test Site #12, was calculated to have poor correlation between all three panels.

It was determined during correlation that the variations in hole wall plating thickness indicated by electrical prescreening were due to variations in the flash plate provided by each test site and not due to variations in electrolytic plating.

Table 4.4 Prescreening Results - 0.013" Vias for All Test Sites[a]

Site #	Mean Res.	Std Dev.	Pnl #1	Pnl #2	Pnl #3	Corr.
1	239	14.5	234	245	237	All
2	252	17.6	269	251	234	2
3	238	12.5	227	248	N/A	All
4	232	11.2	224	239	N/A	All
5	236	12.1	239	241	229	2
6	266	15.7	255	275	266	2
7	253	14.2	240	259	259	All
8	230	11.6	221	228	241	2
9	243	10.6	247	247	235	2
10	248	13.0	256	242	247	All
11	226	19.0	216	221	241	2
12	240	23.0	254	235	231	None
13	231	16.0	243	235	215	2
14	247	26.8	256	227	258	All
15	243	11.1	236	244	248	2
16	239	15.9	232	243	241	All
17	240	12.8	247	243	231	All
18	245	9.7	245	249	240	All
19	226	10.2	223	232	223	2
20	229	10.2	219	238	229	2
21	250	13.3	258	243	249	2
22	256	8.8	256	261	250	All
23	253	12.5	257	257	244	All
24	239	12.0	241	232	246	All
25	224	13.9	210	232	231	All

[a] Site #6, an electroless copper site, may not have performed to its true capability on the day of the test. Due to a malfunction in the line, the electroless copper bath was controlled by manual lab analysis instead of by the usual single-channel controller.

Mean Res. - Mean resistance of all coupons on the three panels.
Std Dev. - Standard deviation for all coupons per test site.
Pnl # - Mean resistance for listed panel.
Corr. - Correlation Coefficient >.7 between each panel.
Sample size for each test site: 12.

Remaining test results will be reported for each type of MHC technology, represented by the following test sites shown in Table 4.5.

Table 4.5 Correlation of MHC Technologies with Test Site Numbers

Test Site #	MHC Technology	# of Test Sites
1 - 7	Electroless Copper	7
8 - 9	Carbon	2
10 - 12	Graphite	3
13 - 22	Palladium	10
23 - 24	Non-Formaldehyde Electroless Copper	2
25	Conductive Polymer	1

Results of Microsection Evaluation

The only defects reported in this study were voids in hole wall copper, drill smear, resin recession, and inner layer separation. Average hole wall thickness was also reported for each panel. Defects present but not included as part of this report are registration, inner layer foil cracks, and cracks in flash plating at the knees of the holes. These defects were not included because they were not believed to be a function of the MHC technology. The inner layer foil cracks appear to be the result of the drilling operation and not a result of z-axis expansion or defective foil. None of the cracks in the flash plating extended into the electrolytic plate in the coupons as received or after thermal stress. Therefore, the integrity of the hole wall was not affected by these small cracks.

Plating Voids. There were no plating voids noted on any of the coupons evaluated. The electrolytic copper plating was continuous and very even with no indication of any voids.

Drill Smear. The panels exhibited significant amounts of nailheading. Since nailheading was present on all panels, it was determined that all test sites had received similar panels to process and therefore, comparisons were possible. The main concern with the presence of nailheading was that the amount of drill smear might be excessive compared to each test site’s “normal” product. Drill smear negatively impacts inner layer connections to the plated hole wall if not removed.

Resin Recession. No samples failed current specification requirements for resin recession. There was, however, a significant difference in the amount of resin recession among test sites.

Inner Layer Separation. Different chemistries had different appearances after metallurgical microetch. Electroless copper microsections traditionally have a definite line of demarcation between foil copper and electrolytic copper after metallurgical microetch. This line also appeared in electroless copper samples in this study. The line is the width of the electroless deposit, and is very important in making a determination as to whether inner layers are separated from the plated hole wall. Many of the products tested in this study had no line of demarcation or lines which had little, if any, measurable width. For those MHC technologies that should not have a line after microetch, the determination as to whether inner layer separation was present on the samples was based on the presence of a line.

Over half of the test sites supplied product which did not exhibit inner layer separations on as received or thermal stressed microsections. Some of the product exhibited inner layer separation in the as received samples which further degraded after thermal stress. Other test sites had product that showed very good interconnect as received and became separated as a result of thermal stress.

The separations ranged from complete, very wide separations to very fine lines which did not extend across the complete inner layer connection. No attempt was made to track these degrees of separation because current specification requirements dictate that any separation is grounds for rejection of the product.

Table 4.6 gives the percentage of panels from a test site that did or did not exhibit a defect. The data are not presented by hole size because only Test Site #11 had defects on only one size of hole. In all other test sites exhibiting defects, the defects were noted on all sizes of holes.

Table 4.6 Proportion of Panels Exhibiting Defects

Test Site #	Percentage of Panels Exhibiting Defect			Percentage of Panels Exhibiting Defect per Technology (average of all test sites)			MHC Technology
	Drill Smr	Res Rec	Post Sep	Drill Smr	Res Rec	Post Sep	
1	0	33	0	21	31.6	31.6	Electroless Copper
2	66	66	100				
3	0	0	0				
4	100	0	0				
5	0	0	0				
6	0	0	100				
7	0	100	0				
8	0	0	0	0	0	0	Carbon
9	0	0	0				
10	0	0	0	0	11	55.6	Graphite
11	0	33	66				
12	0	0	100				
13	0	33	0	3.3	26.5	43.3	Palladium
14	0	0	0				
15	0	0	33				
16	0	0	100				
17	33	33	33				
18	0	33	66				
19	0	100	0				
20	0	0	100				
21	0	0	100				
22	0	66	0				
23	0	0	100	0	0	50	Non-Formaldehyde Electroless Copper
24	0	0	0				
25	0	0	0	0	0	0	Conductive Polymer

Table 4.7 depicts the average measured copper plating thickness for all panels.

Table 4.7 Microsection Copper Plating Thickness (in mils)

Test Site	Panel # 1	Panel # 2	Panel # 3	Average Cu
1	1.4	1.1	1.2	1.24
2	0.95	1.1	1.3	1.11
3	1.3	1.1	N/A	1.2
4	1.3	1.2	N/A	1.25
5	1.2	1.3	1.3	1.24
6	1.1	1.1	1.1	1.1
7	1.5	1.1	1.1	1.2
8	1.3	1.3	1.2	1.3
9	1.2	1.4	1.3	1.3
10	1.0	1.1	1.3	1.14
11	1.5	1.5	1.1	1.4
12	1.3	1.3	1.3	1.3
13	1.2	1.3	1.3	1.3
14	1.2	1.1	1.2	1.2
15	1.1	1.1	1.2	1.13
16	1.1	1.2	1.3	1.2
17	1.2	1.3	1.4	1.3
18	1.1	N/A	1.5	1.3
19	1.5	1.3	1.3	1.4
20	1.6	1.4	1.3	1.4
21	1.1	1.2	1.2	1.14
22	1.2	1.1	1.1	1.13
23	1.4	1.1	1.2	1.24
24	1.3	1.2	1.2	1.23
25	1.4	1.7	1.4	1.5

Results of Interconnect Stress Testing

Test results will be reported in various formats. Both tables and graphs will be used to describe IST cycles to failure for the PTH interconnect and post degradation/separation within the post interconnect. IST was completed on a total of 12 coupons from each test site.

Mean Cycles to Failure Testing Results. The mean cycles to failure for the PTH interconnect are established at the point when the coupon exceeds a ten percent increase in the initial elevated resistance. Mean IST cycles to failure and standard deviation by test site are shown in Table 4.8. Table 4.9 shows the mean IST cycles to failure and standard deviations by MHC technology.

Table 4.8 Mean IST Cycles to Failure, by Test Site

Test Site # & MHC Technology Type	IST Cycles to Fail	Standard Deviation
1 Electroless Copper	346	91.5
2 Electroless Copper	338	77.8
3 Electroless Copper	323	104.8
4 Electroless Copper	384	70
5 Electroless Copper	314	50
6 Electroless Copper	246	107
7 Electroless Copper	334	93.4
8 Carbon	344	62.5
9 Carbon	362	80.3
10 Graphite	317	80
11 Graphite	416	73.4
12 Graphite	313	63
13 Palladium	439	55.2
14 Palladium	284	62.8
15 Palladium	337	75.3
16 Palladium	171	145.7
17 Palladium	370	122.9
18 Palladium	224	59.7
19 Palladium	467	38.4
20 Palladium	443	52.5
21 Palladium	267	40.5
22 Palladium	232	86.6
23 Non-Formaldehyde Electroless Copper	214	133.3
24 Non-Formaldehyde Electroless Copper	261	41.6
25 Conductive Polymer	289	63.1

Sample size = 12 coupons from each site.

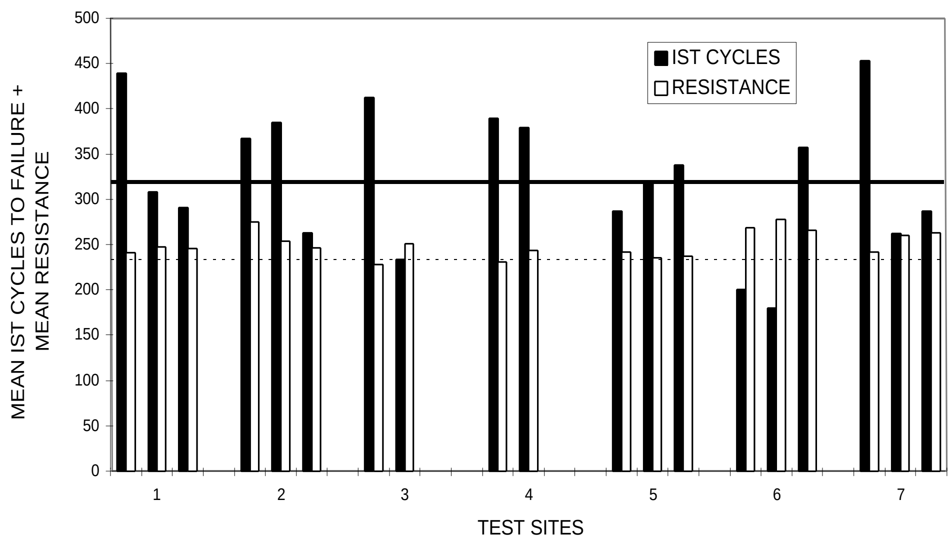
Table 4.9 Mean IST Cycles to Failure, by MHC Technology

MHC Technology	IST Cycles to Fail	Standard Deviation
Electroless Copper	327	92.5
Carbon	354	71
Conductive Polymer	289	63.1
Graphite	349	85.3
Non-Formaldehyde Electroless Copper	238	99.5
Palladium	332	126

High standard deviations indicate that high levels of performance variability exist within and among test sites.

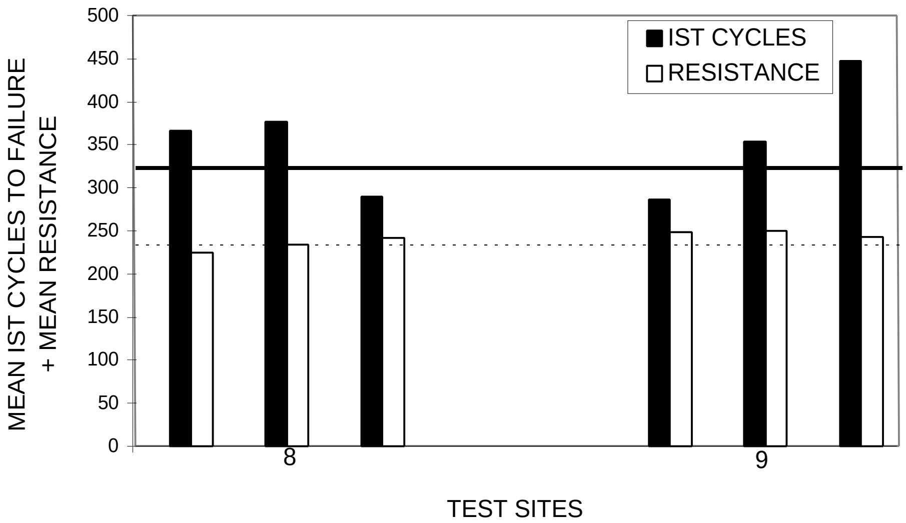
Figures 4.1 through 4.6 identify the IST cycles to failure for each panel and test site for each MHC technology. The two reference lines on each graph identify the mean cycles to failure (solid line) for all 300 coupons tested (324 cycles) and the mean resistance (dotted line) for all coupons measured (241 milliohms). When considering the overall performance of each panel, it is useful to compare the mean resistance of the coupons to the dotted reference line. As mentioned before, each test site was instructed to flash plate 0.0001" of electrolytic copper into the holes. If the sites exceeded this thickness, the total copper thickness would be thicker, lowering the resistance and increasing the performance of the panels. Therefore, panels with lower resistance should be expected to perform better, and vice versa. Although each site was requested to plate 0.0001" of electrolytic copper, the actual range was between 0.00005" and 0.0005".

Figure 4.1 Electroless Copper - IST Cycles to Fail vs. Resistance



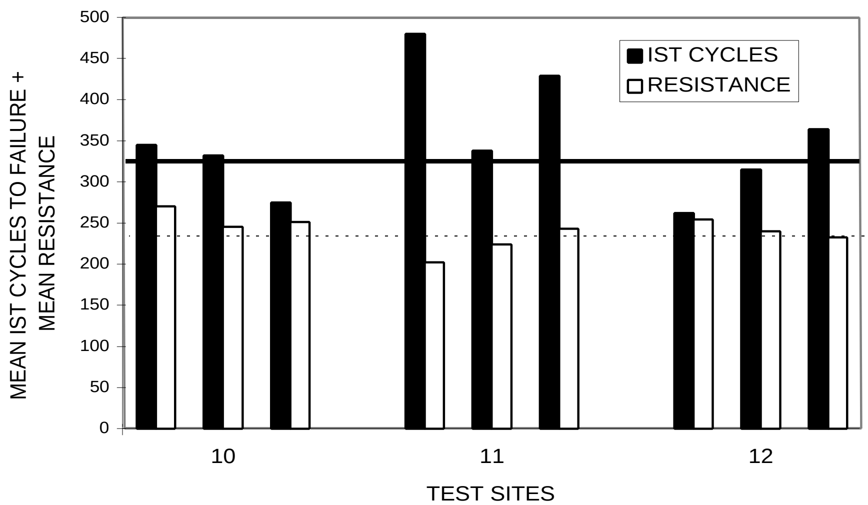
All electroless copper test sites had at least one panel that met or exceeded the mean performance. As shown in Figure 4.1, for the panels that did not achieve the mean performance, it can be seen that the mean resistance column was above the reference line (thinner copper). The exception was Test Site #6, which exhibited a high degree of post separation (see post separation results section below for an explanation of results). As noted previously, Test Site #6 may not have performed to its true capability on the day of the test. Due to a malfunction in the line, the electroless copper bath was controlled by manual lab analysis instead of by the usual single-channel controller.

Figure 4.2 Carbon - IST Cycles to Fail vs. Resistance



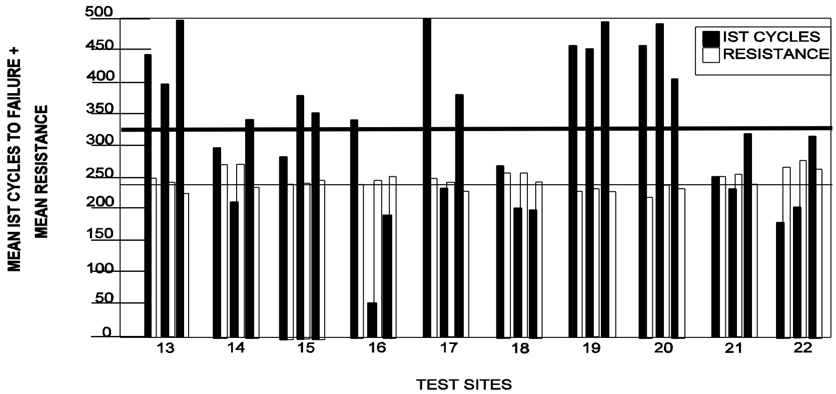
As shown in Figure 4.2, both carbon test sites had at least two panels that met or exceeded the mean performance.

Figure 4.3 Graphite - IST Cycles to Fail vs. Resistance



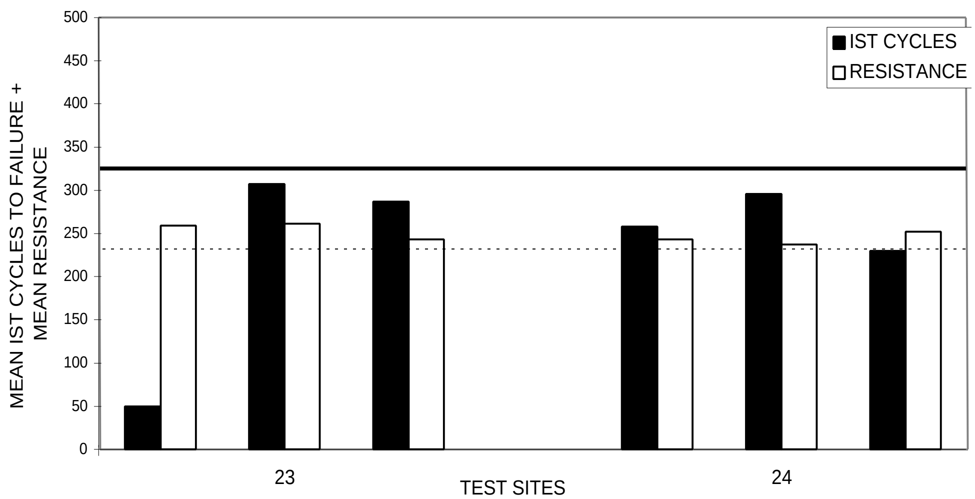
All three graphite test sites had at least one panel that met or exceeded mean performance, as shown in Figure 4.3.

Figure 4.4 Palladium - IST Cycles to Fail vs. Resistance



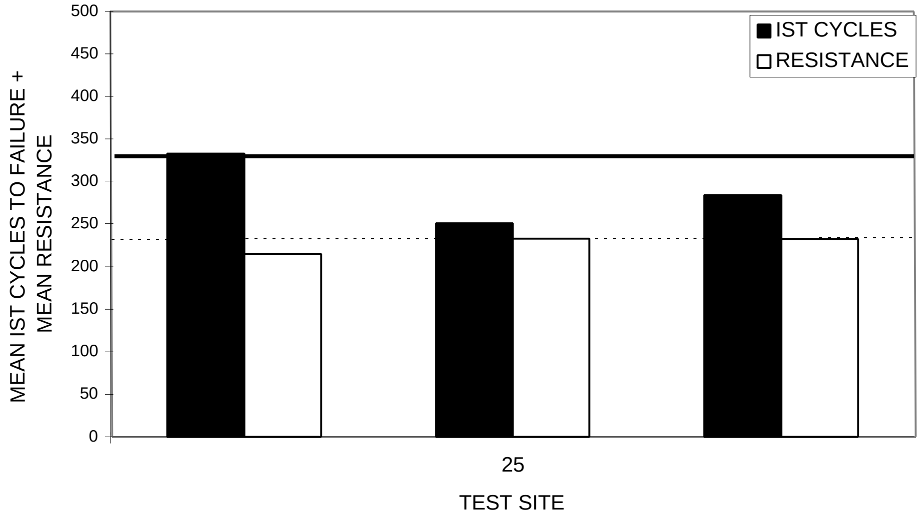
As shown in Figure 4.4, most palladium test sites had at least one panel that met or exceeded the mean performance. Three test sites did not. Those test sites that did not achieve the mean performance exhibited either high resistance or post separation.

Figure 4.5 Non-Formaldehyde Electroless Copper - IST Cycles to Fail vs. Resistance



Neither non-formaldehyde electroless copper test site met or exceeded mean performance, as shown in Figure 4.5. Test Site #23 exhibited a high degree of post separation (see post separation results section below for an explanation of results).

Figure 4.6 Conductive Polymer - IST Cycles to Fail vs. Resistance



As shown in Figure 4.6, the single conductive polymer test site had one panel that met or exceeded the mean performance.

<u>Post Separation Testing Results</u>

IST determines post interconnect performance (post separation) simultaneously with the PTH cycles to failure performance. The failure criteria for post separation has not been established. Further work is in progress with the IPC to create an accept/reject criteria. For this study, the IST rejection criteria is based on a 15 milliohm resistance increase derived from the mean resistance degradation measurement for all 300 coupons tested.

A reliable post interconnect should measure minimal resistance degradation throughout the entire IST. Low degrees of degradation (<15 milliohms) are common and relate to the fatigue of the internal copper foils. Resistance increases greater than 50 milliohms were reported as 50 milliohms. This was done in order to avoid skewing results.

The mean resistance degradation of the post interconnect is determined at the time the PTH failed. The readings (in milliohms) for the post interconnect and the standard deviations for each test site (sample size = 12 coupons from each site) and for each MHC technology are shown in Tables 4.10 and 4.11, respectively.

Table 4.10 Mean Resistance Degradation of Post Interconnect, by Test Site (in milliohms)

Test Site # and MHC Technology Type	Post Degradation	Standard Deviation
1 Electroless Copper	13.1	3.5
2 Electroless Copper	17.2	12.9
3 Electroless Copper	6.6	3.7
4 Electroless Copper	6.7	2.7
5 Electroless Copper	3.8	2.4
6 Electroless Copper	34.8	13.1
7 Electroless Copper	4.1	4.6
8 Carbon	2.8	2.9
9 Carbon	2	2.5
10 Graphite	5.2	3.9
11 Graphite	8	8.1
12 Graphite	16	15
13 Palladium	9.5	4.7
14 Palladium	2.8	2.6
15 Palladium	7.9	7.4
16 Palladium	32.2	18.1
17 Palladium	0.8	1.8
18 Palladium	7.6	6.4
19 Palladium	4.7	3.3
20 Palladium	13.7	5.6
21 Palladium	40.5	11.3
22 Palladium	4.5	2.6
23 Non-Formaldehyde Electroless Copper	47.9	7.2
24 Non-Formaldehyde Electroless Copper	4.2	1.9
25 Conductive Polymer	2.8	1.8

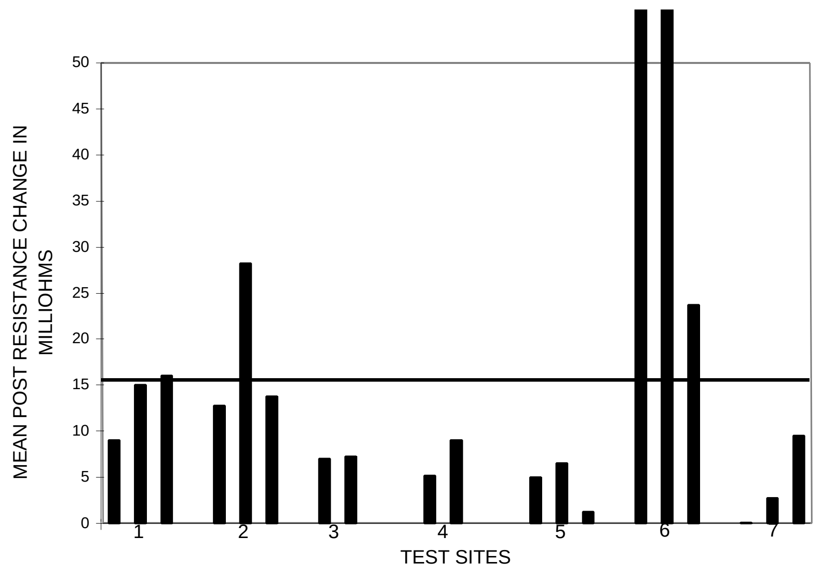
Table 4.11 Mean Resistance Degradation of Post Interconnect, by MHC Technology

MHC Technology Type	Post Degradation	Standard Deviation
Electroless Copper	12.3	12.6
Carbon	2.4	2.7
Conductive Polymer	2.75	1.8
Graphite	9.7	10.8
Non-Formaldehyde Electroless Copper	26	22.9
Palladium	12.4	14.3

High standard deviations indicate that high levels of variability exist within and among test sites and within an MHC technology.

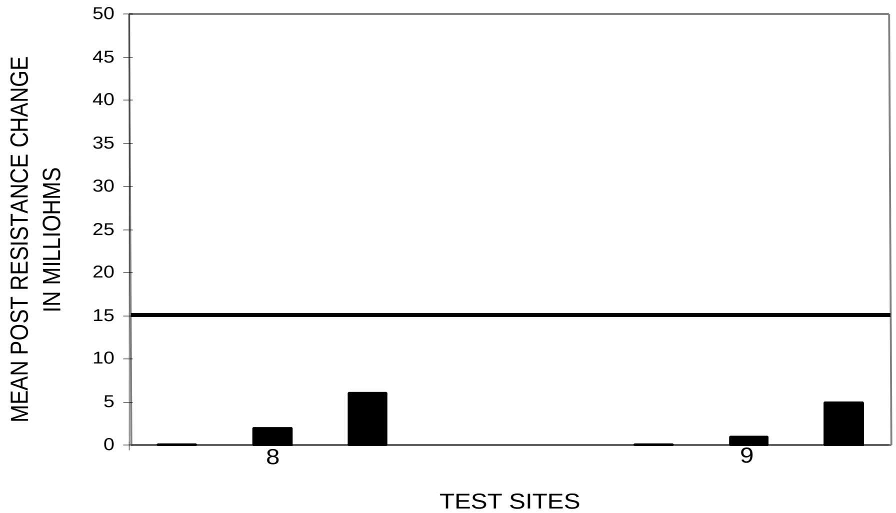
Figures 4.7 through 4.12 identify the mean (average of four coupons per panel) IST post resistance degradation results. The reference line on each graph identifies the mean resistance degradation measurement for all 300 coupons tested (15 milliohms). If the mean resistance degradation column is above the reference line, the panel had coupons that exhibited post separation. The post resistance change was the value recorded at the point where the PTH (barrel) failed.

Figure 4.7 Electroless Copper - Post Resistance Degradation



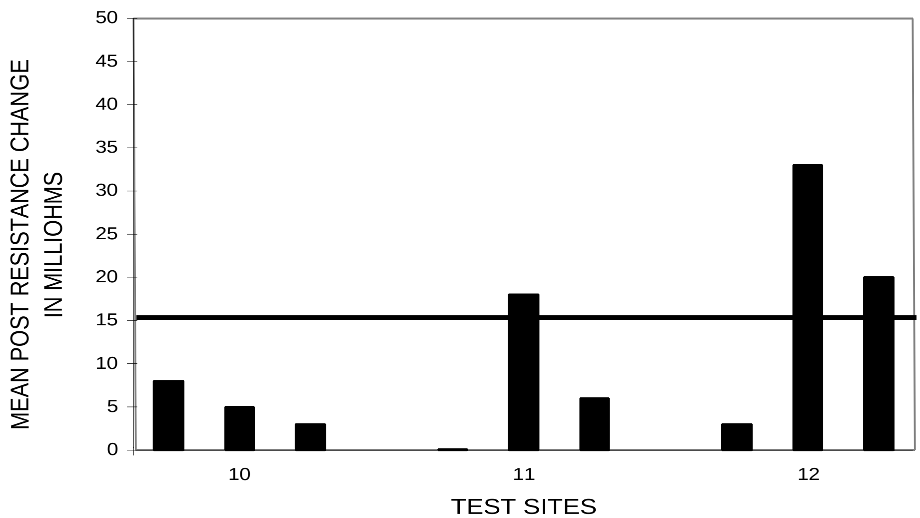
As shown in Figure 4.7, two of the seven electroless copper test sites had at least one panel that exhibited post separation. All three panels from Test Site #6 clearly exhibited gross post separation. Both test methods for post separation failed all panels from Test Site #6. As noted previously, Test Site #6 may not have performed to its true capability on the day of the test. Due to a malfunction in the line, the electroless copper bath was controlled by manual lab analysis instead of by the usual single-channel controller.

Figure 4.8 Carbon - Post Resistance Degradation



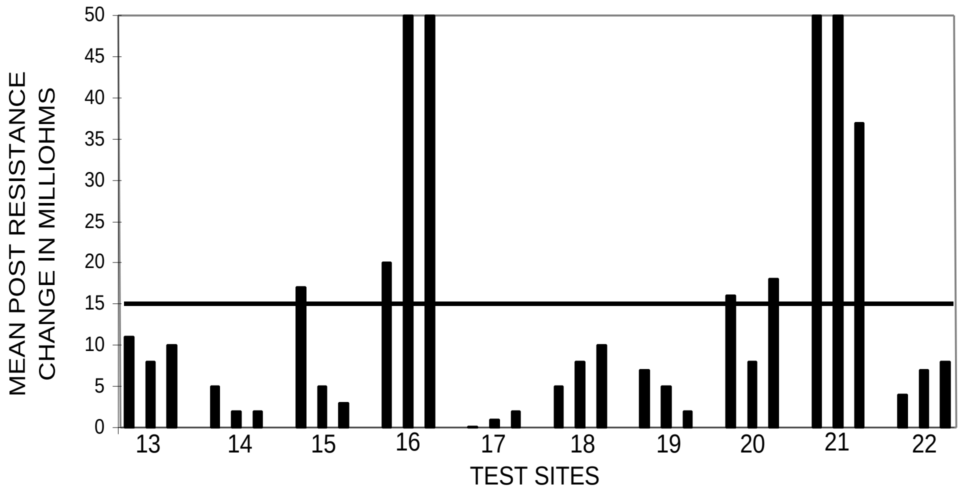
No post separation was detected on any carbon panels, as shown in Figure 4.8.

Figure 4.9 Graphite - Post Resistance Degradation



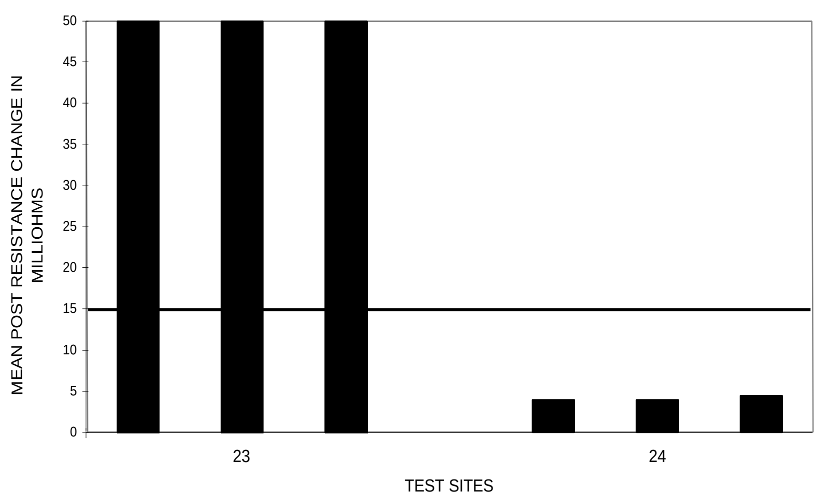
As shown in Figure 4.9, two of the three graphite test sites had at least one panel that exhibited post separation.

Figure 4.10 Palladium - Post Resistance Degradation



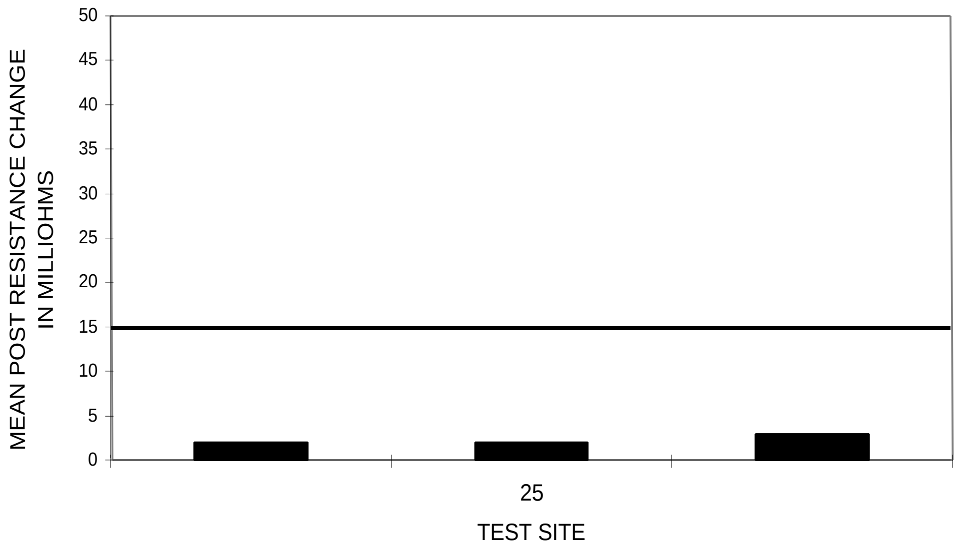
As shown in Figure 4.10, four of the ten palladium test sites had at least one panel that exhibited post separation. Test Site #16 and Test Site #21 clearly exhibited gross post separation.

Figure 4.11 Non-Formaldehyde Electroless Copper - Post Resistance Degradation



As shown in Figure 4.11, all three panels for non-formaldehyde electroless copper Test Site #23 clearly exhibited gross post separation.

Figure 4.12 Conductive Polymer - Post Resistance Degradation



No post separation was detected on any conductive polymer panels, as shown in Figure 4.12.

4.1.6 Comparison of Microsection and IST Test Results

Microsection and IST were run independently, and test results were not shared until both sets of data were completed and delivered to EPA. To illustrate the consistency of the test results, Table 4.12 identifies both test methods and their results for post separation detection.

"Y" or "N" (yes or no) denote whether post separation was detected on any coupon or panel from each test site. The "panels affected" column refers to how many of the panels within each test site exhibited post separation. Test Site #17 was the only site with post separation found in the microsection but not on IST.

Post separation results indicated percentages of post separation that were unexpected by many members of the industry. It was apparent that all MHC technologies, including electroless copper, are susceptible to this type of failure. The results of this study further suggest that post separation may occur in different degrees. The level of post separation may play a role in determining product performance; however, the determination of levels of post separation remains to be discussed and confirmed by the PWB industry.

Table 4.12 IST/Microsection Data Correlation

Test Site #	Microsection	Panels Affected	IST	Panels Affected
1	N	0	N	0
2	Y	3	Y	3
3	N	0	N	0
4	N	0	N	0
5	N	0	N	0
6	Y	3	Y	3
7	N	0	N	0
8	N	0	N	0
9	N	0	N	0
10	N	0	N	0
11	Y	2	Y	1
12	Y	3	Y	2
13	N	0	N	0
14	N	0	N	0
15	Y	1	Y	1
16	Y	3	Y	3
17	Y	1	N	0
18	Y	2	Y	2
19	N	0	N	0
20	Y	3	Y	2
21	Y	3	Y	3
22	N	0	N	0
23	Y	3	Y	3
24	N	0	N	0
25	N	0	N	0